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Long Term Trends of Size Distribution for Eastern Hemlock in West Michigan Dune Forests

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Abstract:
Size distributions of trees often yield valuable clues about changing environmental conditions and the responses of populations to them. In a recent study, we measured the size distribution of Eastern Hemlocks in several forests near Lake Michigan to determine whether active recruitment into the population is taking place at a similar rate as in the past. The diameter at breast height of trees was measured for a large sample of hemlocks in selected stands. Analysis showed that the size distribution was strongly skewed toward the intermediate and larger size classes ($p < 0.001$), suggesting a failure of recent recruitment relative to that in the past. Potential reasons for this decline in recruitment include, but are not limited to, herbivory by deer and possibly climatic changes in the last few decades (increasing temperatures and decreasing precipitation rates). Other studies in the Lake Michigan region, both inland and coastal, have documented declines in hemlock populations based on sample data and paleoecological trends. If the observed trend continues into the future, Eastern Hemlock will most likely continue to decline in density in these forests over the long term.

Background:
Eastern Hemlock (*Tsuga canadensis*) is a major component of the boreal forest at high latitudes across North America. It is also a significant component of forests along the western coast of Michigan and the shore of Lake Superior, on the dune systems formed since the end of the last glaciation. These forests have a unique composition owing to the microclimate created by their proximity to Lake Michigan (to approx. 900m inland) and to the topography created by the stabilized dunes (Grittinger 2009, Stuart et al. 2012). *T. canadensis* seems to be in decline in many of these forests however, owing to low recruitment driven by multiple environmental and anthropogenic factors (Salk et al. 2011). In forests near Lake Superior, low recruitment appears to have started in the 1970's (Salk et al. 2011), and appears to be attributable more to herbivory by white-tailed deer (*Odocoileus virginianus*) than to climate change (Frelich and Lorimer 1985). According to reports by the Michigan DNR, white-tailed deer populations grew by approximately one million between 1937 and 1989. Our current goal is to assess the level of recent recruitment into populations of *T. canadensis* in coastal regions of southwest Michigan and to determine if any declines can be attributed to herbivory by deer.

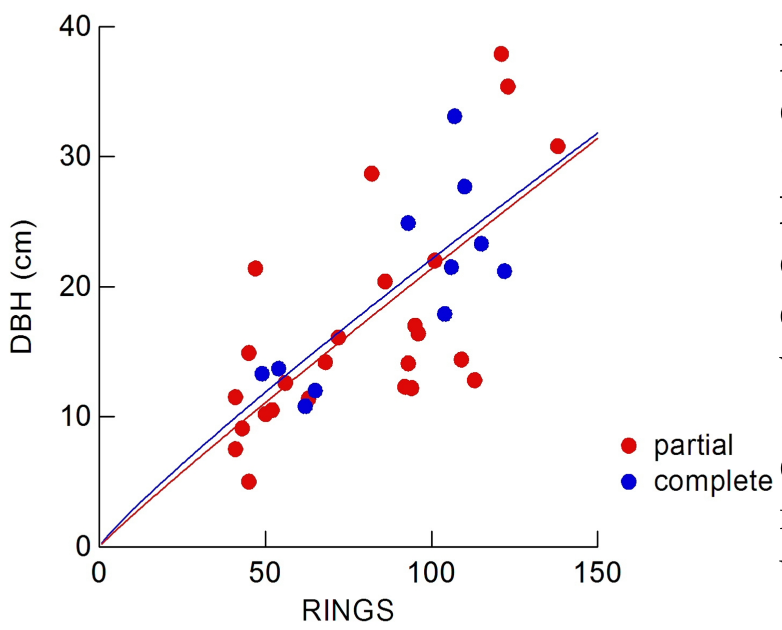


Figure 1. Annual growth rings vs. diameter at breast height (dbh) in *T. canadensis* in and near the HCNP. Lines are best nonlinear fits of the form dbh = a * rings^b to the data for all trees (red) and for those with complete cores (blue). For the 11 "full" core records, the regression equation was dbh = 0.357 * rings$^{0.896}$. For all trees combined it was dbh = 0.273 * rings$^{0.947}$.

Figure 4. Enclosure for hemlock seedlings.

Figure 5. Unprotected hemlock seedling.

Study Area and Methods:
In 1995, Dr. K. Greg Murray and his students established a 20 x 20 m grid system at the Hope College Nature Preserve (HCNP; 42.747ºN, 86.198ºW) in Allegan County and began to tag, identify, and measure all trees $\geq$ 10 cm dbh (diameter at breast height; 1.37m above soil level). In 2013, 133 quadrats (5.32 hectares) were searched thoroughly to include all hemlocks less than 10 cm dbh as well. We also censused hemlocks of all sizes at two other sites in 2013: Rosy Mound Natural Area (43.019ºN, 86.226ºW) and North Ottawa Dunes County Park (43.086ºN, 86.252ºW), both in Ottawa County. All of these forests are considered transitional deciduous forest, dominated by American Beech (*Fagus grandifolia*), Sugar Maple (*Acer saccharum*), White Pine (*Pinus strobus*), and others, though they are unique in that they include a significant number of Eastern Hemlocks as well. In 2012 we took increment cores from 37 trees ranging from 5 to 45 cm dbh at the HCNP to estimate the relationship between dbh and age. To explore the effects of herbivory and microclimate on hemlock recruitment, we transplanted hemlock seedlings (30-50 cm tall) at all three sites in spring 2013 in four treatment combinations: deer-protected vs. unprotected on north- vs. south-facing slopes. Seedlings were protected using wood-framed exclosures covered with wire mesh (2.5 cm mesh), approx. 22 cm diameter x 45 cm tall. N- and S-facing slopes were chosen to explore the effects of microclimate because S-facing slopes are warmer and more xeric than N-facing ones. Seedlings were obtained in February 2013 and maintained in the greenhouse until they were transplanted between 23 April and 11 June 2013.

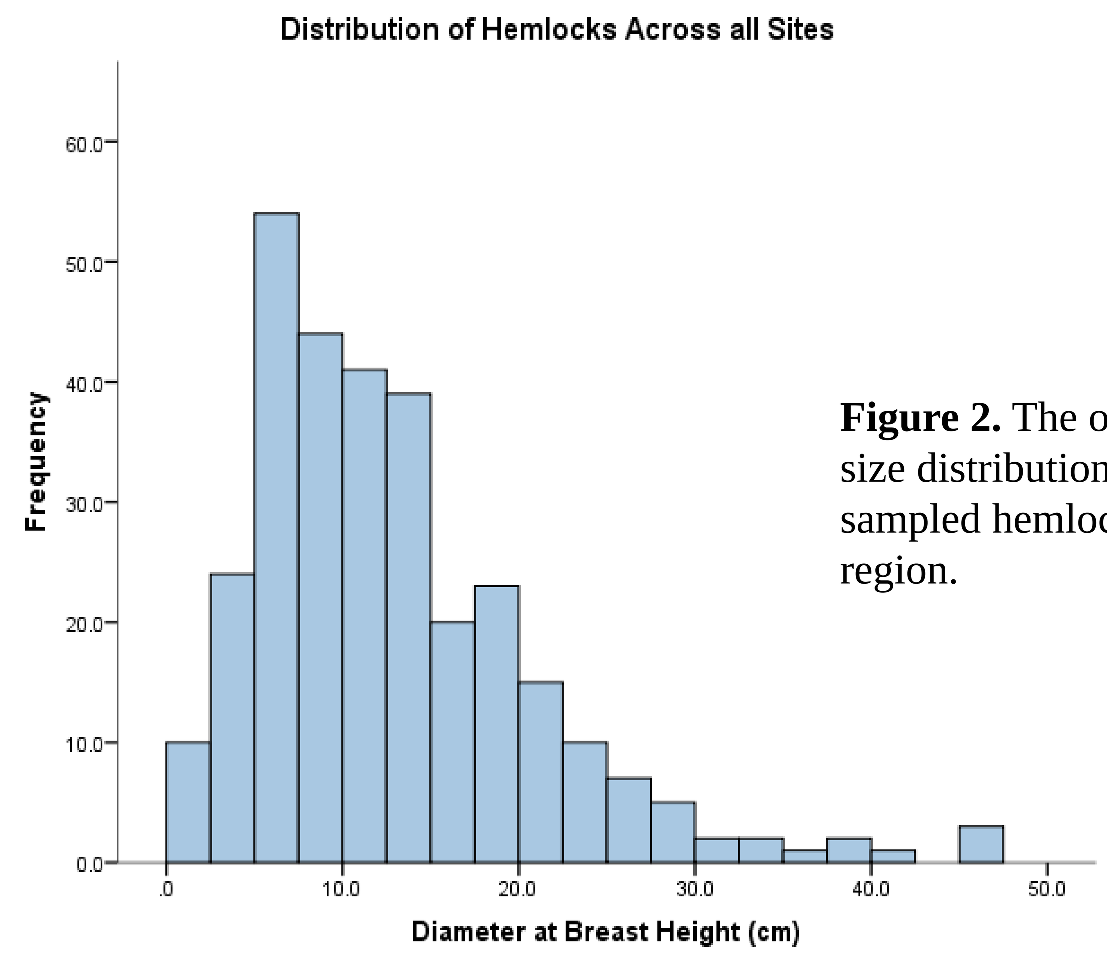
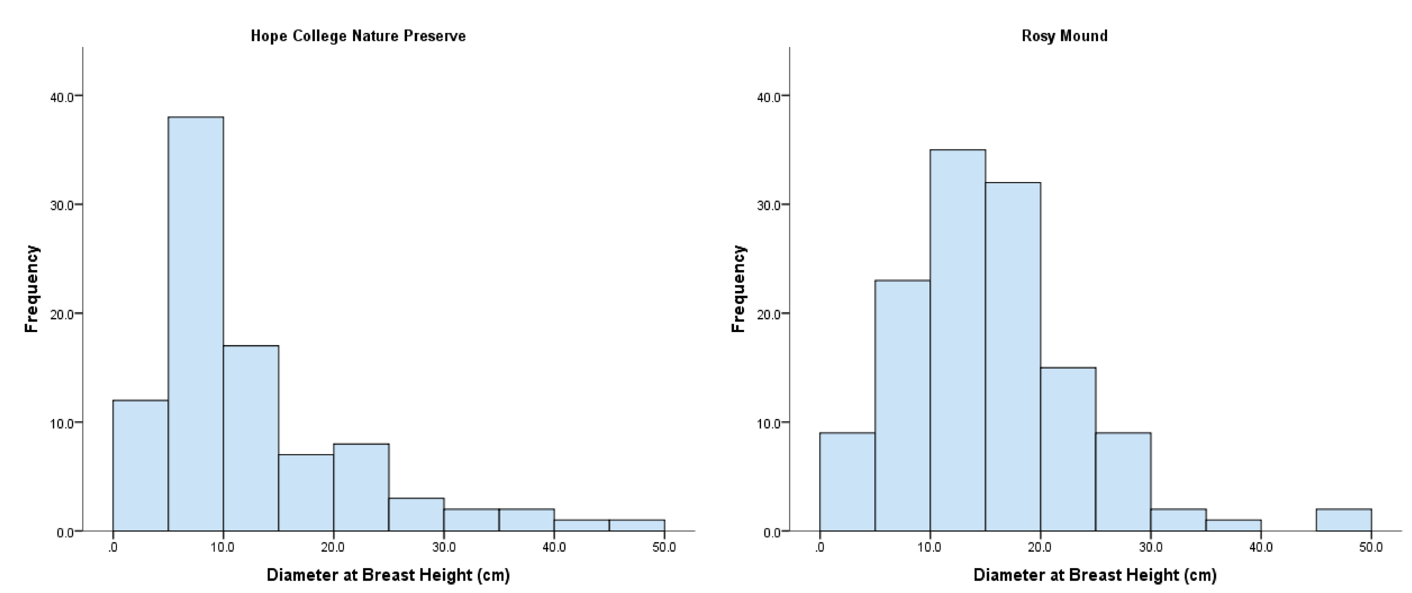


Figure 2. The overall size distribution of sampled hemlocks in the region.



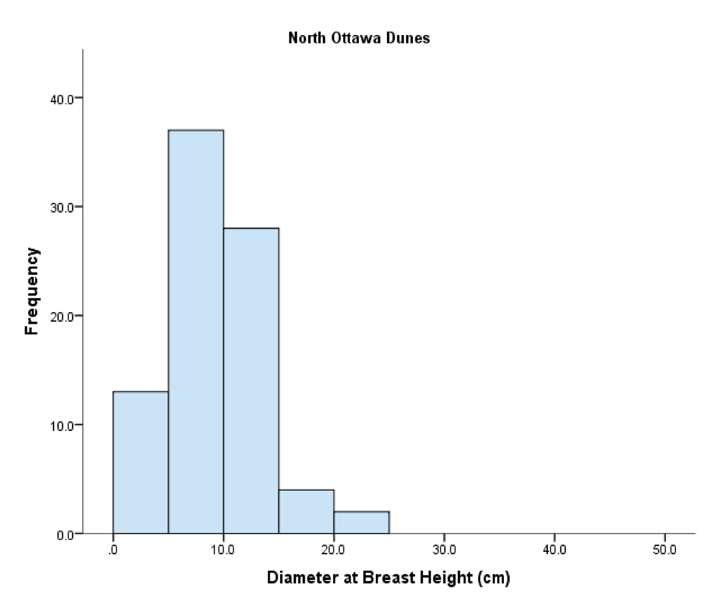


Figure 3. Size distribution of hemlocks at each survey site. Analysis showed that there was a significant difference in size distribution across all three sites ($p<0.001$).

Results:
Age-size relationship - We used nonlinear regression to fit curves of the form dbh = a * rings^b to the data from trees from which increment cores were collected (fig. 1). In general, hemlocks at the HCNP grew to only 11-12 cm diameter in 50 years.
Size distributions - In all, 303 Eastern Hemlocks were censused at the three sites: 91 at the HCNP, 84 at NOD, and 128 at Rosy Mound. The modal size class was 5-10 cm at the HCNP and North Ottawa Dunes, while at Rosy Mound it was 10-15 cm. Although the distributions were all unimodal (figs. 2 and 3), they differed significantly from one another, with mean dbh being slightly higher at Rosy Mound (15.5 cm), intermediate at the HCNP (12.4 cm), and smallest (8.8 cm) at North Ottawa Dunes (Kruskal-Wallis one-way analysis of variance; H = 45.977 w/ 2 df; $p<0.001$). Modal dbh at RM, the HCNP, and NOD corresponded to 62.9, 36.7, and 34.2 years of growth (fig. 1).
Survival of transplanted seedlings - In late November 2013, all transplanted seedlings at the sites were still alive, showing no signs of browsing by deer.

Discussion:
The size (and, hence, age) distributions in figures 2 and 3 suggest that *T. canadensis* recruitment at all three sites has been much lower in the last 35-60 years than it was historically. Tree populations with healthy annual recruitment have J-shaped size distributions; i.e., the smallest individuals comprise the most frequent size class, and larger trees are less frequent due to self-thinning and other mortality factors. Healthy populations of *T. canadensis* elsewhere indeed have such distributions (e.g., Hett and Loucks 1976). However, across our three sites, only 11.2% of the trees are younger than 19 years (5 cm dbh), while 32.4% are between the ages of 19 and 45 years (5-10 cm dbh; fig. 2). Low recruitment in these populations is of particular concern because *T. canadensis* is a diagnostic component of the dune forests that fringe the eastern shore of Lake Michigan. In forests near Lake Superior studied by Frelich and Lorimer (1985), low recruitment was believed to result primarily from herbivory by whitetailed deer. But given its restriction to sites with high soil moisture and moderate temperature, the species should also be very susceptible to the effects of climate change in our region. Indeed, *T. canadensis* may be an ideal species for detecting changes in the environment (Hessl and Pederson 2012). It is possible that a combination of factors has restricted recruitment into populations in our region (Grittinger 2009). Other factors could also be involved, of course, including competition with other species such as Maple and American Beech (Rooney and Waller 1998) or a decrease in the woody litter that holds moisture and thereby facilitates Hemlock establishment (D'Amato et al. 2008).

Figure 6. Panoramic view of a north facing slope at the HCNP.

Acknowlegements
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